

Report for 2002WA12G: Collaborative Research:Hydraulic and Geomorphic Controls on the Evolution of Cluster Bedforms in Gravel-Bed Streams

- Conference Proceedings:
 - Hendrick, Ross R., Lisa L. Ely, A. N. Papanicolaou, and Kyle B. Strom, 2004, The role of geomorphic and hydrologic feature on sediment clusters in gravel-bed streams, Washington: A field-based approach, "in" Abstracts with Programs, Geological Society of America Rocky Mountain/Cordilleran Section Meeting, Boise, Idaho, May 3-5, 2005, 36(4):31.
 - Hendrick, Ross R., Ely, Lisa L., Marcell, Janielle L., Papanicolaou, Athanasios N., and Strom, Kyle B., 2005, Tracking the Evolution of Sediment Clusters after High Flow Events, and their Effects on Sediment Transport: Entiat River, Washington: A Field-Based Approach, "in" Abstracts with Programs, Geological Society of America, 37(4):103.
 - Marcell, Janielle L., Ely, Lisa L. and Hendrick, Ross R., 2005, Evolution of Sediment Cluster Morphologies on the American River, Cascade Mountains, Washington, "in" Abstracts with Programs, Geological Society of America, 37(4):45.
- Other Publications:
 - Strom, Kyle, Athanasios N. Papanicolaou,B. Billing, Lisa L. Ely, and Ross R. Hendricks, 2005 Characterization of Particle Cluster Bedforms in Mountain Streams. Presentation at the World Water and Environmental Resources Congress, EWRI, ASCE, May 15-19, 2005.
 - Marcell, Janielle, 2004, Patterns of Sediment transport in the American River, Cascade Mountains, Washington (poster presentation) "in" Thirteenth Regional Conference on Undergraduate Research, Murdock College Science Research Program, Lewis and Clark College, November 19-20, 2004.

Report Follows

PROBLEM AND RESEARCH OBJECTIVES

1. Develop a stage-discharge relation to determine the required flow conditions for cluster development and disintegration in the field at the American and Entiat River sites.
2. Analyze the flux of individual sediment particles through cluster bedforms.
3. Characterization of Particle Cluster Bedforms at the American River site.

METHODOLOGY

Stage data for the American River site was collected and logged for high flows in 2003 and 2004 with the Global Water Instruments water-level recorder, which was installed at the site in Spring, 2003. The discharge at the Entiat River was determined directly from the USGS gage. Channel cross sections were surveyed on both rivers, and velocities at the American and Entiat River sites were calculated using the HEC-RAS water-surface profile model.

Clusters were marked, photographed and surveyed before and after each major high-flow event. Sediment movement within individual clusters was analyzed from photographs.

To achieve objective 3 data were recorded at the site, for the reach-scale stream morphology, stream slope, grain size distribution, cluster type, and geometric properties. Five main types of clusters were identified. Namely the comet, heap, line, pebble, and ring shaped clusters. These cluster types can be roughly correlated to other cluster types noted in the literature from field and laboratory studies. Descriptive cluster geometry ratios are presented to aid in defining artificial cluster creation in numerical and analytical modeling of flow over a clustered bed.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Entiat River Study Site. On the Entiat River, the evolution of cluster bedforms and movement of individual sediment particles within clusters were monitored for 4 peak flows that inundated the study site. The peak flows were Oct., 2003, $57 \text{ m}^3\text{s}^{-1}$; Nov. 2003, $13 \text{ m}^3\text{s}^{-1}$; May 2004, $39 \text{ m}^3\text{s}^{-1}$, and Jan. 2005, $22 \text{ m}^3\text{s}^{-1}$. Sediment cluster bedforms had a measurable impact on sediment entrainment during the two intermediate flow events of 22 and $39 \text{ m}^3\text{s}^{-1}$ that inundated the gravel bar at the study site. Under these flows, the critical shear stress required to entrain sediment particles was 38-51% greater for sediment within clusters than for isolated sediment particles on the gravel bar. All clusters were mobilized during the highest peak in the 2-year record, $57 \text{ m}^3\text{s}^{-1}$, which occurred in October, 2003. Therefore the clusters did not significantly impact the overall sediment transport during this event, as the entire bed was mobilized at the study site. No measurable sediment movement occurred within the clusters during the lowest inundation event of $13 \text{ m}^3\text{s}^{-1}$. The mean annual peak flow on the Entiat River is $\sim 80 \text{ m}^3\text{s}^{-1}$, which means that on average, sediment clusters on this river are likely at least partially mobilized and reformed on a semi-annual basis. At site 1 on the Entiat River, which had a fairly well-sorted sediment size distribution, the diamond cluster form was the most stable over the 2-year period. At site 2, with a greater range of sediment sizes and larger anchor clasts, all cluster forms were equally stable.

American River Study Site.

The current study has examined the shape and geometric properties of naturally occurring cluster microforms on a mountainous gravel bed river. Our focus was the evolution of the cluster morphologies during periods of moderate peak flows. It was our hypothesis that this evolution

would only occur during moderate flow conditions because during high flow periods the clusters would be completely reorganized.

Five main types of discrete cluster microforms were observed, those being the pebble, line, comet, heap, and ring type clusters. Although deciphering cluster shape is subjective, examining cluster geometric properties reveals that there are physical differences among cluster types. These physical differences might be related to a point at which a cluster is in its evolutionary cycle. In addition, individual cluster types and their associated shapes are also likely to effect the way in which a particular cluster type will effect sediment transport and the near bed flow field. If we wish to understand the accumulative effect of a clustered bed on river hydraulics and sediment transport, we must identify individual cluster types and account for the effects these have on the turbulent structure of the the flow. The geometric ratios presented here in could be used as a first approximation to defining cluster topography in modeling efforts.

On the American River the 2003 peak flow was 31.5 m³/sec and the 2004 peak flow was 24 m³/sec, which are moderate-sized annual peaks compared to the historic record. Our hypotheses were that 1) transverse line clusters are incipient forms that would ultimately transform into upstream or downstream triangles; 2) upstream and downstream triangle clusters are intermediate cluster forms which ultimately form diamond clusters; and 3) diamond clusters are the final cluster form and are therefore the most stable. The results were that no flows during the 2-year period were sufficient to mobilize the sediment clusters, and all cluster forms were therefore stable throughout the study period. In contrast, individual sediment particles were added, moved and removed from the clusters. The diamond clusters experienced the greatest amount of individual sediment movement through the stable cluster bedforms and the transverse lines the least.

The field study areas on both rivers have experienced below-average peak flows during the 2-year study period. This period of low to moderate flows was advantageous because we were able to investigate the flux of sediment through the stable cluster forms without the complete destruction and reorganization of the clusters. Understanding the sediment movement through the clusters helps determine the sediment flux and transport patterns throughout the stream. The response of the channel bed morphology to flows in unregulated rivers such as the Entiat and American Rivers, has practical implications for river management, channel restoration and maintenance of aquatic habitat in regulated streams by guiding the determination of peak discharges necessary to maintain or mobilize cluster bedforms.

Additional analyses underway include: 1) continued examination of critical shear stresses involved in sediment entrainment, 2) determination of cluster density at different sites, 3) incorporation of sediment and flow data into the 3STID flow model at the University of Iowa to refine the bed-velocity calculations at the cluster sites and 4) analysis of the geomorphic settings of gravel clusters.

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